Vermont Rivers & Roads Field Manual

Prepared by the Vermont Department of Environmental Conservation in cooperation with the Vermont Agency of Transportation

VERMONT DEPARTMENT OF ENVIRONMENTAL CONSERVATION
WATERSHED MANAGEMENT DIVISION
RIVERS PROGRAM

VERMONT FISH & WILDLIFE

VTrans Working to Get You There
Vermont Agency of Transportation

Information Resources

Rivers and Roads Training Program Materials
www.watershedmanagement.vt.gov/rivers.htm

ANR River Management Standard Principles and Practices
www.watershedmanagement.vt.gov/rivers/docs/VT_SRMPP_1st_edition.pdf

The Cross-Vane and J-Hook Vane Structures, Dave Rosgen
www.wildlandhydrology.com/assets/cross-vane.pdf

Boulder Clusters Technical Note
el.erdc.usace.army.mil/elpubs/pdf/sr11.pdf

ANR River Management Engineer and Permit Information
www.watershedmanagement.vt.gov/rivers/htm/rv_management.htm

USGS Stream Stats Tool
water.usgs.gov/osw/streamstats/Vermont.html

ANR Natural Resources Atlas
anrmaps.vermont.gov/websites/anra/

Vermont Aquatic Organism Passage Information
www.vtfishandwildlife.com/fisheries_AOP.cfm

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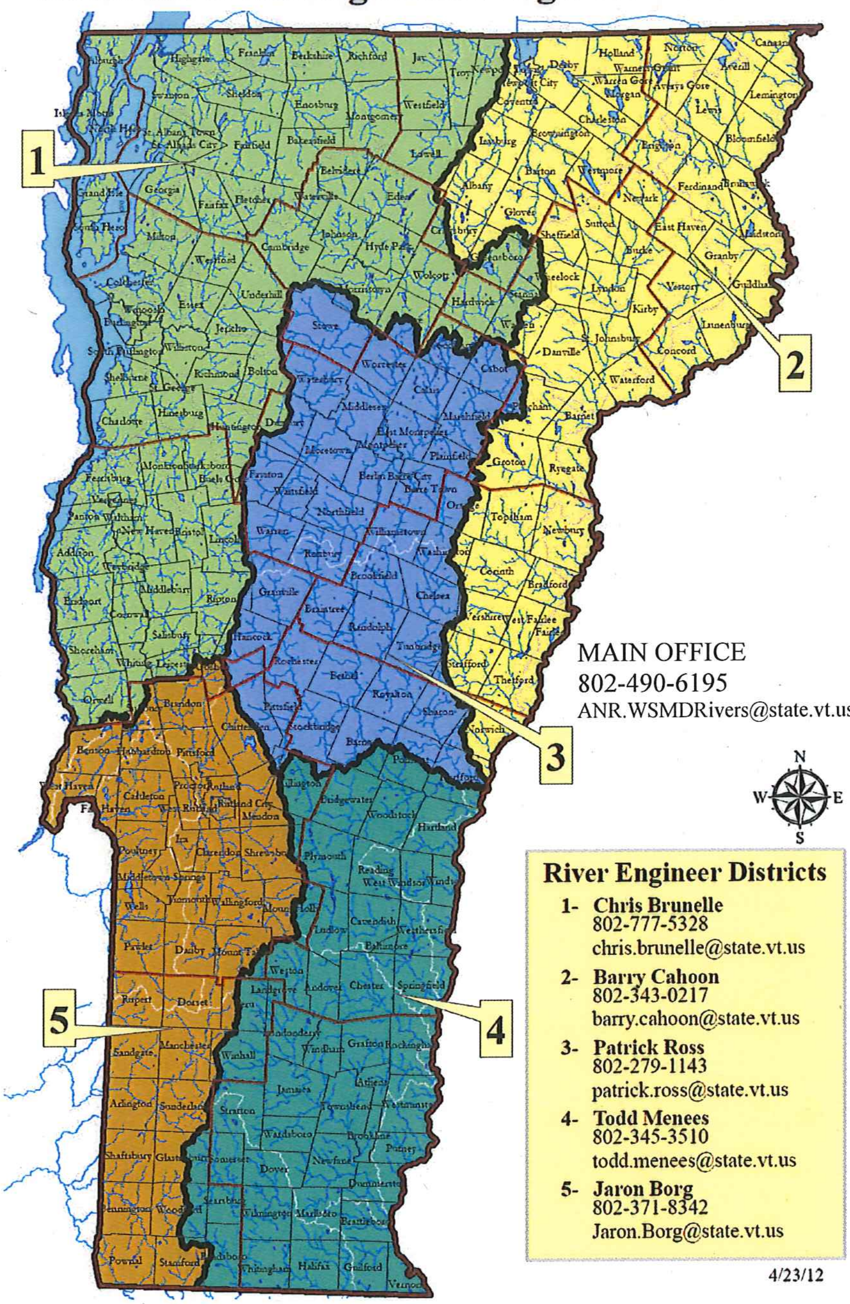
Introduction

Rivers are shaped by processes that result in general stability over time but periodic disturbances, both natural and human caused can destabilize a river and result in damage to adjacent infrastructure. This field manual is a guide to linking flood damages to river instability and designing flood recovery projects that restore the river and road to a more stable condition.

Contents

ANR River Management Engineer Districts



A Step-Wise Procedure for Building River Stability into Road Repair and Construction Projects

It is critical to understand the scale and type of river instability that caused the site damages that you see. Whether confronted with acute flood damages or chronic river and road instability, use the following steps to understand the instability of the river and how to rebuild the road in a manner that maximizes river and road stability.

1. Determine the expected river morphology using available information including:
   Valley and River Types (use topographic maps)
   Hydrologic and Sediment Regime Impacts (use online aerial photography)
   Drainage Area (use USGS Stream Stats)
   Channel Dimensions (use VT Channel Dimensions Table)

2. Determine the existing morphology: Make the following observations and measurements.

   Observations
   - Bed Morphology
   - Planform and Deposition Patterns
   - Bed Erosion
   - Bank Erosion
   - Stabilizing Features

   Measurements
   - Bankfull Stage
   - Bankfull Dimensions
   - Entrenchment
   - Incision

3. Understand the instability: Compare the existing morphology to the expected morphology to determine the type, scale and cause of channel adjustments.

4. Design the restoration: Use your understanding of the expected condition, channel evolution and standard river management practices to restore infrastructure while returning the river to a configuration that is as close to the equilibrium condition as possible.

Expected Morphology

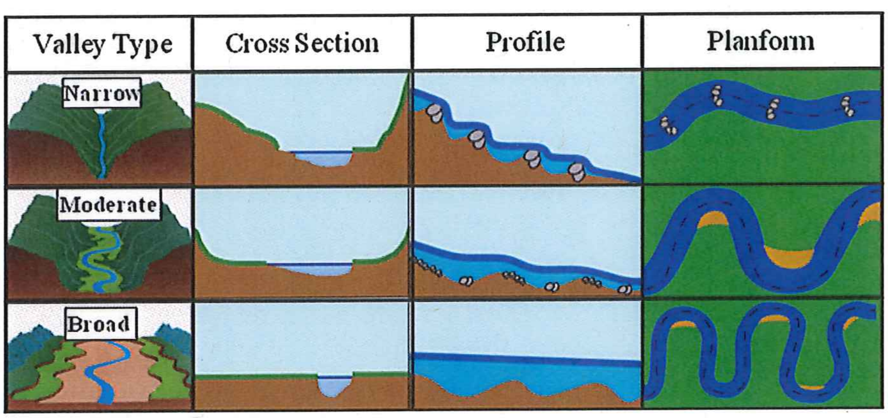
Stable rivers have a predictable form that is determined by valley setting, watershed size and land use. Use the following information to determine the expected morphology.

Valley Setting and Stream Type

Observe the valley setting on the ground and use the tables below to identify the corresponding channel type.

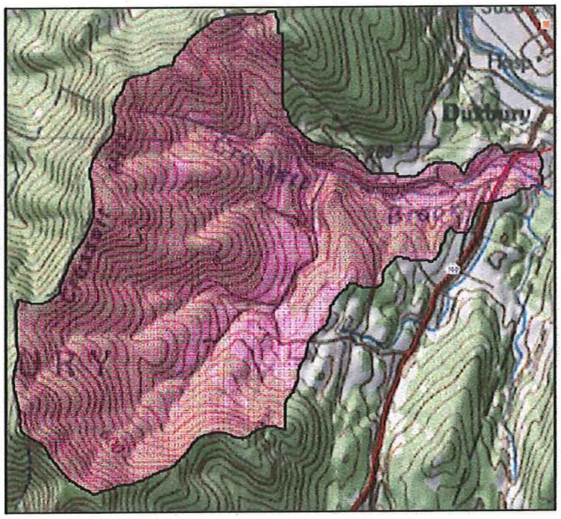
Typical Channel Types of Vermont

	Steep Narrow Valley	Moderate Slope and Width Valley	Flat and Wide Valley
Channel Slope	2% and Great-er	Less than 2%	Less than 2%
Sinuosity	Low	Medium	High
Entrenchment	1.4 – 2.2	Greater Than 2.2	Greater Than 2.2
Width / Depth	12 - 20	20 - 30	Less Than 12
Bed Forms	Cascade and/ or Step-Pool	Riffle-Pool	Ripple-Dune
Bed Material	Gravel, Cobble and Boulder	Sand, Gravel and Cobble	Sand



Expected Morphology

Drainage Area and Hydrologic and Sediment Regimes



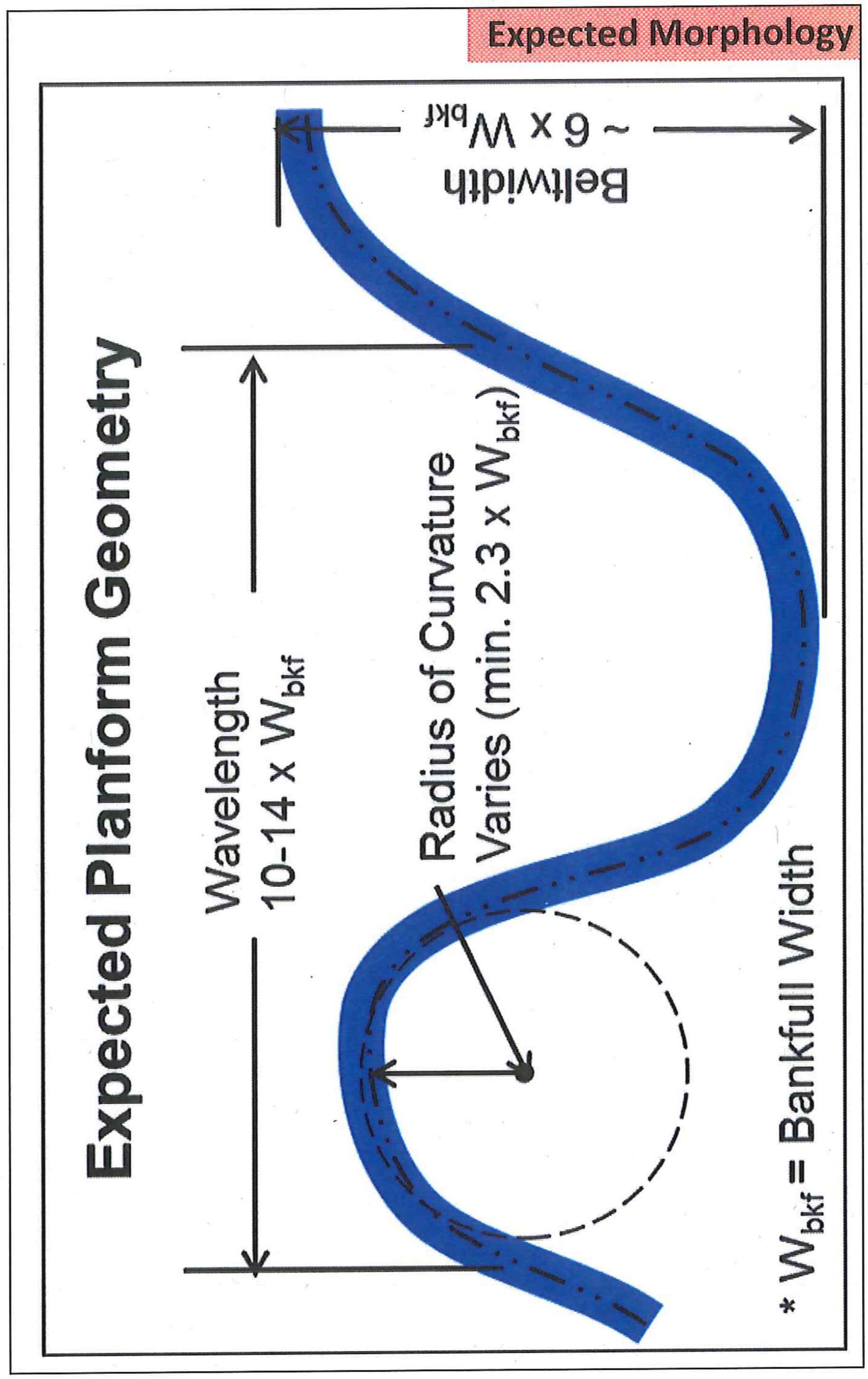
Drainage area is a good predictor of channel dimensions. Use the USGS Stream Stats tool to measure drainage area and channel slope.
http://streamstats.usgs.gov/Vermont.html

A site will be affected by upstream land-use. Use aerial photography to get a sense of the amount of hydrologic and sediment regime alteration in the watershed.
http://anrmaps.vermont.gov/websites/anra/

Expected Morphology

Planform Geometry

- Rivers in moderate and broad valleys and not controlled by bedrock typically have well developed meanders.
- Planform Geometry describes the shape of a river's meanders (see next page).
- The most important measures of planform geometry are shown on the next page and include:
    - Wavelength
    - Radius of Curvature
    - Beltwidth
- The expected values of these measures is shown on the following page.
- Planform geometry can change regularly and such changes don't necessarily indicate serious instability as long as the river isn't incised. However, comparing the existing to the expected planform geometry can help strengthen your opinion of whether a river is stable or not.


Expected Morphology
Expected Planform Geometry
Wavelength
10-14 x W_{bkf}
Radius of Curvature
Varies (min. 2.3 x W_{bkf})
Beltwidth
~ 6 x W_{bkf}
* W_{bkf} = Bankfull Width

Expected Morphology

Use the table below to determine the approximate expected bankfull width and depth of the river. Expect natural variability. Steep rivers tend to be slightly wider and flat rivers tend to be slightly narrower than values predicted by the tables. Use the table to get you in the ball-park.

Vermont Bankfull Channel Dimensions Table

Drainage Area (mi^2)	Bankfull Width (ft.)	Bankfull Depth (ft.)	Drainage Area (mi^2)	Bankfull Width (ft.)	Bankfull Depth (ft.)
3	21	1.3	46	71	3.0
4	24	1.5	50	73	3.1
5	27	1.6	55	76	3.2
6	29	1.6	60	79	3.3
7	31	1.7	65	82	3.4
8	33	1.8	70	85	3.4
9	34	1.9	75	88	3.5
10	36	1.9	80	90	3.6
12	39	2.0	85	93	3.6
14	42	2.1	90	95	3.7
16	44	2.2	95	97	3.8
18	47	2.3	100	99	3.8
20	49	2.4	105	102	3.9
22	51	2.4	110	104	3.9
24	53	2.5	115	106	4.0
26	55	2.6	120	108	4.0
28	57	2.6	125	110	4.1
30	59	2.7	130	112	4.1
34	62	2.8	135	113	4.2
38	65	2.9	140	115	4.2
42	68	2.9			

*Channel Width = $13.1 \times D.A.^{0.44}$. ($R^2 = 0.91$)

*Channel Depth = $0.96 \times D.A.^{0.30}$. ($R^2 = 0.87$)

*Drainage area can be measured using the U.S. Geological Survey Stream Stats Tool at http://streamstats.usgs.gov/Vermont.html

Existing Morphology

Make on-site observations and measurements to determine the existing morphology.

On-Site Observations

Features	Description
Nick-Points or Head-cutting	Steep to vertical and erodible drops in the channel bed? The banks downstream of the drops are significantly higher than the banks upstream.
Excessive Deposition	Large rapidly growing point bars and/or mid-channel bars. Coarse bed materials and bed features buried by finer material. Generally loose, unarmored bed material.
Lack of bed features	A lack of stable steps on steep streams. A lack riffle-pool sequences on moderate and flat streams.
Rapid Bank Erosion	Freshly exposed roots and/or actively failing banks.
Stabilizing Features	Natural or manmade features such as bedrock or a stable culvert that could provide some degree of resistance to further bed or bank erosion.

On-Site Measurements

- Bankfull Stage
- Bankfull Width and Depth
- Entrenchment Ratio
- Incision Ratio

Note: See figures on pg 12

Existing Morphology

Bankfull Channel Dimensions

Bankfull Stage

- The discharge that shapes and maintains the channel over the long term is called the bankfull discharge because it typically fills a stable channel to the top of its banks. The height of the bankfull discharge is called the bankfull stage.
- The bankfull discharge is a moderate size flow that occurs every-other year on average, typically during spring runoff.
- The bankfull discharge creates visual evidence of its height that remains long after the water has receded.
- The bankfull stage provides a consistent benchmark for measuring width and depth that is independent of the water surface.
- The bankfull stage is synonymous with the Army Corps of Engineers' Ordinary High Water Elevation (OHW).

Determining the Limits of the Bankfull Channel

1. Find 3-5 bankfull indicators along the channel and measure the height of each above the water surface.
2. If the height of most of the indicators are within half a foot of each-other, calculate their average. This is height of the bankfull discharge.
3. If the heights of the indicators are not within half a foot of each other continue identifying indicators until you find at least three that have the same height.
4. Use the bankfull height above water surface as a benchmark for measuring bankfull width and depth of the channel.

Bankfull Indicators

The bankfull discharge leaves evidence of its height in the form of flat landforms covered with sands and fine gravels that have been deposited by the river. Look for these features as indicators of the height of the bankfull discharge.

- **The nearly flat and vegetated top of stable point bars.** On stable meandering rivers the tops of point bars usually mark the bankfull stage. Don't use the tops of large bars made up of coarse materials. These are often rapidly growing and don't provide good indicators of the bankfull stage.

- **Flat benches along the banks.** On straighter sections of river the bankfull stage is often marked by the top of flat benches that protrude out from higher banks.

- **Break in bank slope.** The point at which the steep bank transitions to a flatter slope often marks the bankfull stage.

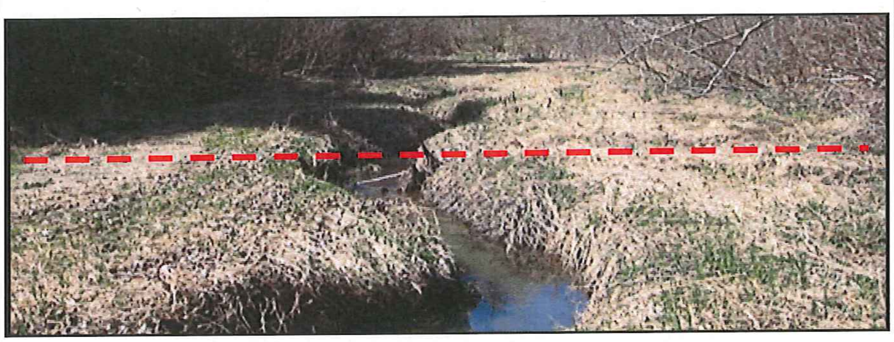
- **Lower limits of trees.** Because bankfull flow occurs fairly often most trees cannot grow within the bankfull channel. Do not use trees that have slumped into the channel over time.

Existing Morphology

Example Bankfull Channels

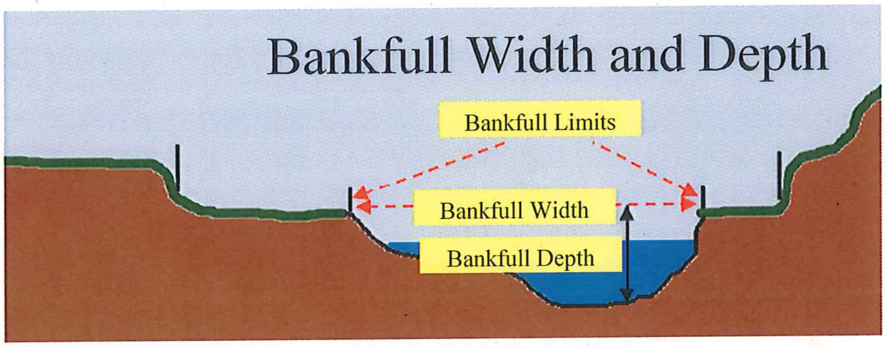
Steep entrenched brook in a narrow valley

Moderate gradient non-entrenched brook in a broad valley

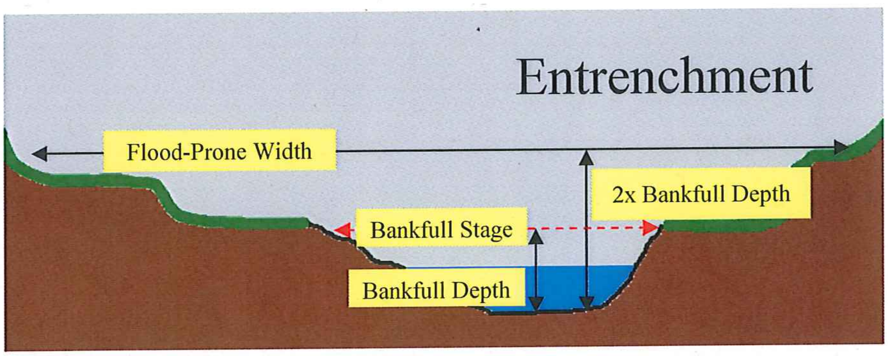


Low gradient non-entrenched brook in a broad valley

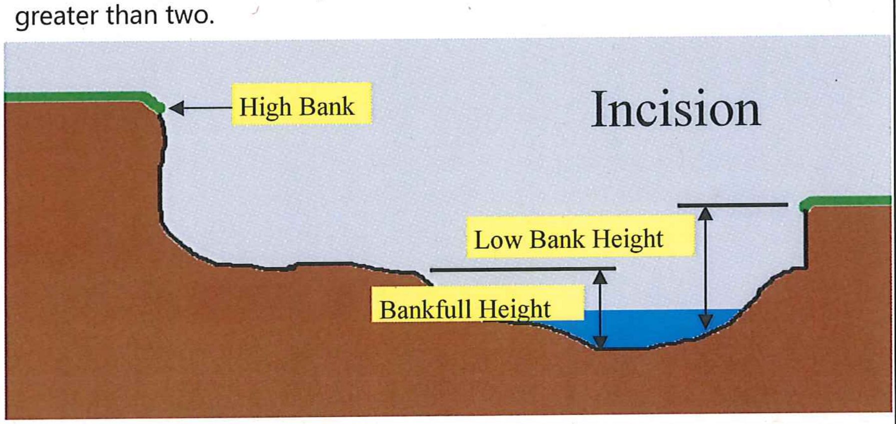
Existing Morphology



Measure bankfull width and depth at the elevation of the bankfull limits



Entrenchment is the ratio of flood-prone width to bankfull width. Moderate and broad valley rivers should have an entrenchment value greater than two.



Incision is the ratio of the height of the low bank to the bankfull depth. An incision ratio greater than 1.2 indicates channel incision.

Understanding Instability

Compare the existing and expected morphology to determine the type, scale and cause of instability and what practices should be implemented to restore the damaged infrastructure and move the river toward an equilibrium condition.

Analysis Questions

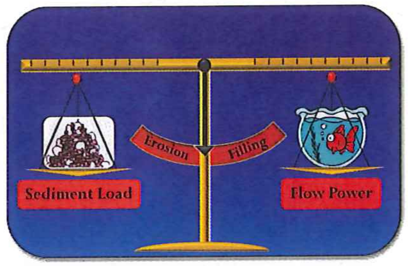
- Does the existing channel type match the expected?
- Has the river incised to the extent that it has lost floodplain connectivity?
- Is the river filling to the extent that the bankfull discharge would jump the banks and abandon the channel?
- Are the expected bedforms and other channel roughness elements present?
- Has the river narrowed or widened by 25% of the expected width?
- Is lateral instability being caused by vertical instability?
- Do your observations suggest the channel has moved into channel evolution (see pgs 16 and 17)?

Causes of River Instability

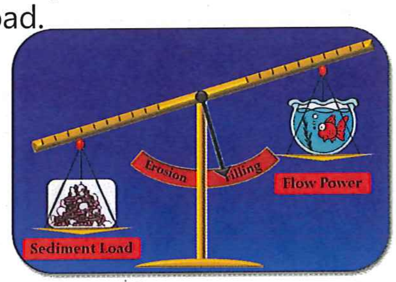
Instability Type	Causes
Erosion (vertical and/or lateral)	Increased discharge, slope, or depth
	Decreased roughness (lost bed features)
Filling	Increased sediment load/size
	Decreased discharge, slope or depth

Understanding Instability

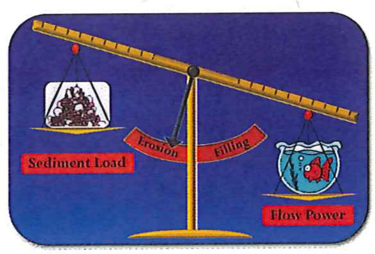
Identifying the Necessary Actions



This channel is stable. Width and depth are as expected for a moderate valley river and riffle-pool bedforms are in place. Flow power is in balance with channel resistance and sediment load.



This narrow valley channel was filled during a landslide. Flow power is overwhelmed by the sediment load. Restore by dredging to create a bankfull width and depth channel and rebuilding step-pool bedforms.

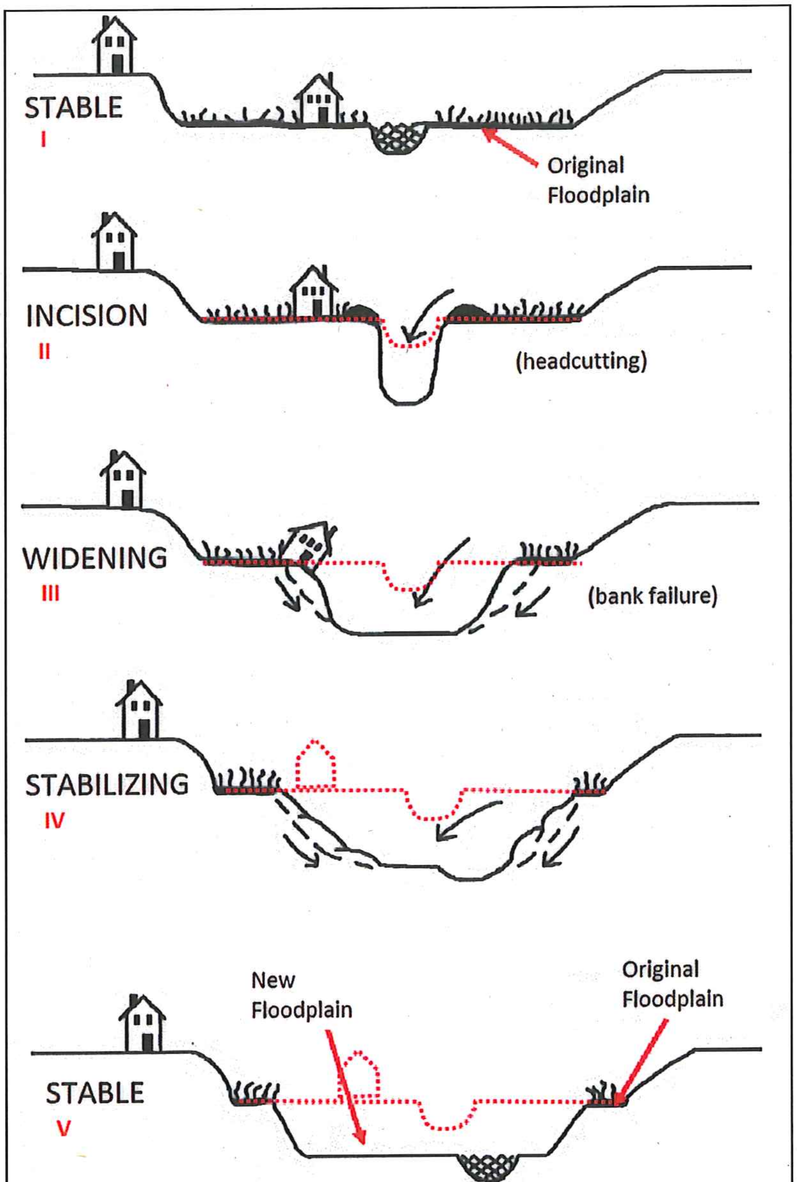


This broad valley channel has a greater width and depth than expected and no bedforms. It has incised over ten years. The flow power overwhelms the resistance of the channel and the sediment load. Restore by reconnecting the channel and floodplain, narrowing width, and restoring channel roughness.

Understanding Instability

Channel Evolution

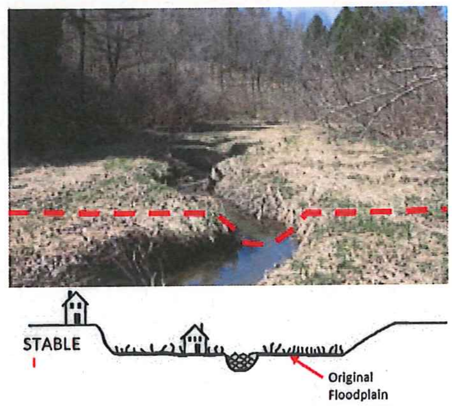
Channel Evolution can last for tens to hundreds of years. Recognize it and identify channel modifications that will advance the river toward the stable stage.

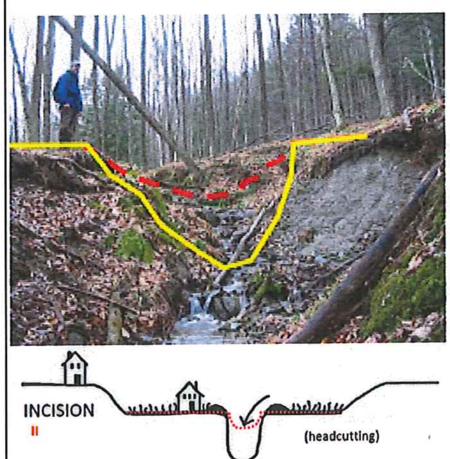


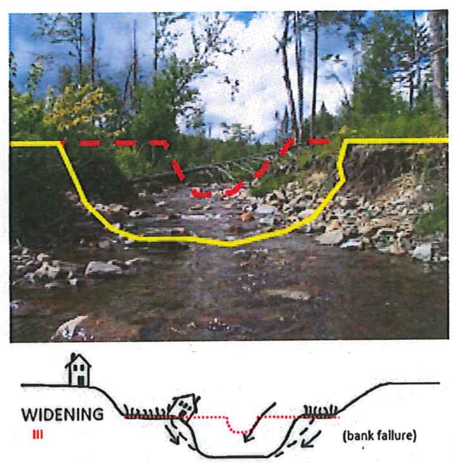
Understanding Instability

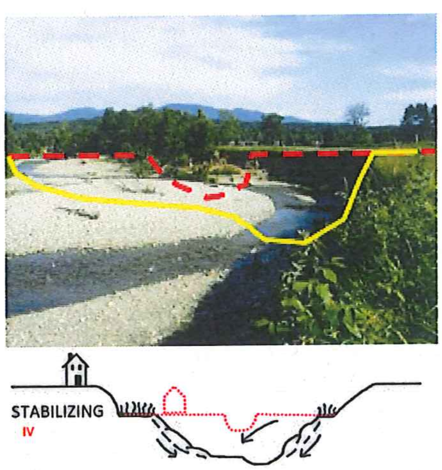
Stages of Channel Evolution

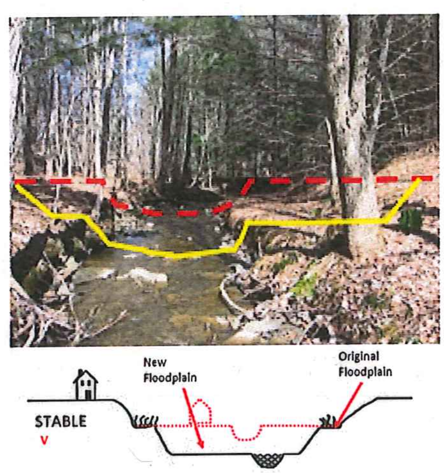
Examples from Vermont











Design

At this point you know what the upstream, downstream, expected and existing conditions are. You also understand the reach scale adjustments that have led to the existing condition, the probability of further adjustments and the risk those adjustments pose to surrounding infrastructure.

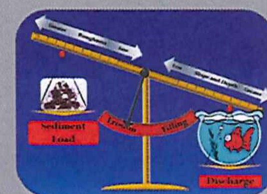
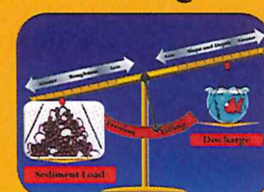
Next select one or more of the standard practices listed in the next section to re-establish the expected morphology of the river to the greatest extent possible while also restoring damaged infrastructure.

General Design Considerations

- Restore the predicted or observed bankfull width and depth dimensions. Or, if the damaged reach lies between two altered but undamaged reaches, match the dimensions of the up and downstream reaches.
- Restore the expected degree of floodplain connectivity to the greatest extent possible.
- Leave in place or construct bed features to provide roughness and habitat.
- Stabilizing a channel that has incised can require significant design work. Consider getting technical assistance with solutions.
- If stabilization structures are required, follow the design specifications closely (see the next section of examples of commonly used stabilization structures).
- Keep in mind the likely channel response to the activities listed in the table on the following page and try to avoid them.
- Follow the Stream Alterations Culvert Standards when replacing culverts to ensure preservation of sediment and flow transport and overall river stability and aquatic organism passage.

Design

River and Road Maintenance Activities to Avoid

Activity		Resulting Change to Equilibrium Factors	Channel Response
Over Dredging	→	Increased Depth	Erosion 
Over Dredging	→	Decreased Resistance & Sediment Volume	
Channel Narrowing	→	Increased Depth	
Channel Berming	→	Increased Depth	
Channel Straightening	→	Increased Slope	
Increased Runoff Rate	→	Increased Depth & Slope	
Undersized Culvert	→	Decreased Slope Upstream	Filling 
Channel Widening	→	Decreased Depth	
Upstream Landslides	→	Increased Sediment Volume	

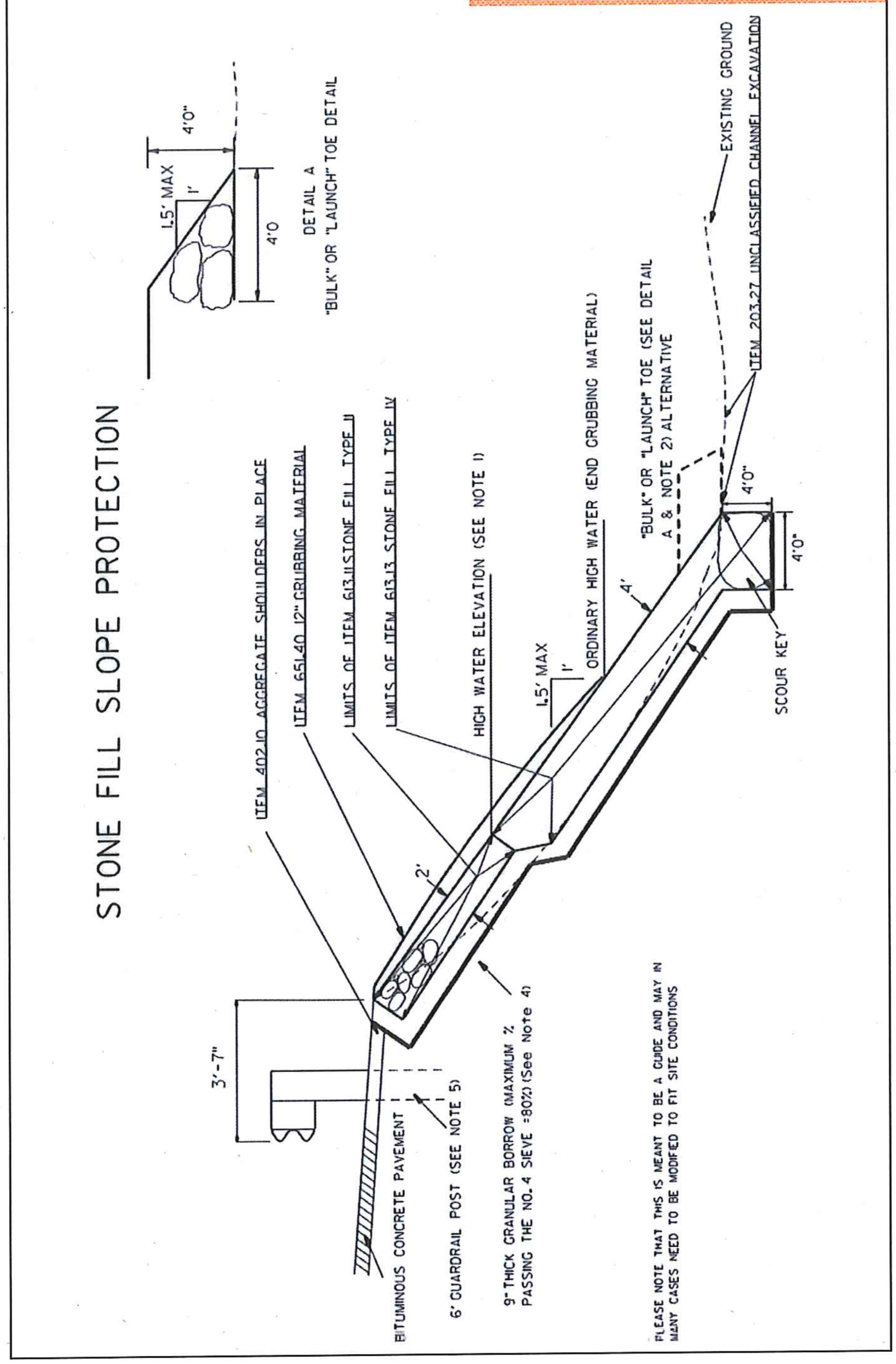
Standard Practices

Stone Fill

Figure 1. *Stone Fill serves as an immobile surface that protects the underlying bank from erosion.*

CONSIDERATIONS

- Slope
- Material Gradation
- Thickness
  - Keyway (vertical and lateral)
  - Top Elevation (1 ft above low floodplain on opposite bank or Q50)
- Underlayment/Bedding


STONE FILL SLOPE PROTECTION
ITEM 402.10 AGGREGATE SHOULDERS IN PLACE
ITEM 651.40 12" GRUBBING MATERIAL
LIMITS OF ITEM 613.11 STONE FILL TYPE II
LIMITS OF ITEM 613.13 STONE FILL TYPE IV
HIGH WATER ELEVATION (SEE NOTE 1)
1.5' MAX
1'
ORDINARY HIGH WATER (END GRUBBING MATERIAL)
"BULK" OR "LAUNCH" TOE (SEE DETAIL A & NOTE 2) ALTERNATIVE
ITEM 203.27 UNCLASSIFIED CHANNEL EXCAVATION
EXISTING GROUND
SCOUR KEY
4'
4'0"
4'0"
2'
3'-7"
BITUMINOUS CONCRETE PAVEMENT
6' GUARDRAIL POST (SEE NOTE 5)
9" THICK GRANULAR BORROW (MAXIMUM % PASSING THE NO. 4 SIEVE =80%) (See Note 4)
PLEASE NOTE THAT THIS IS MEANT TO BE A GUIDE AND MAY IN MANY CASES NEED TO BE MODIFIED TO FIT SITE CONDITIONS
1.5' MAX
1'
4'0"
4'0
DETAIL A
"BULK" OR "LAUNCH" TOE DETAIL

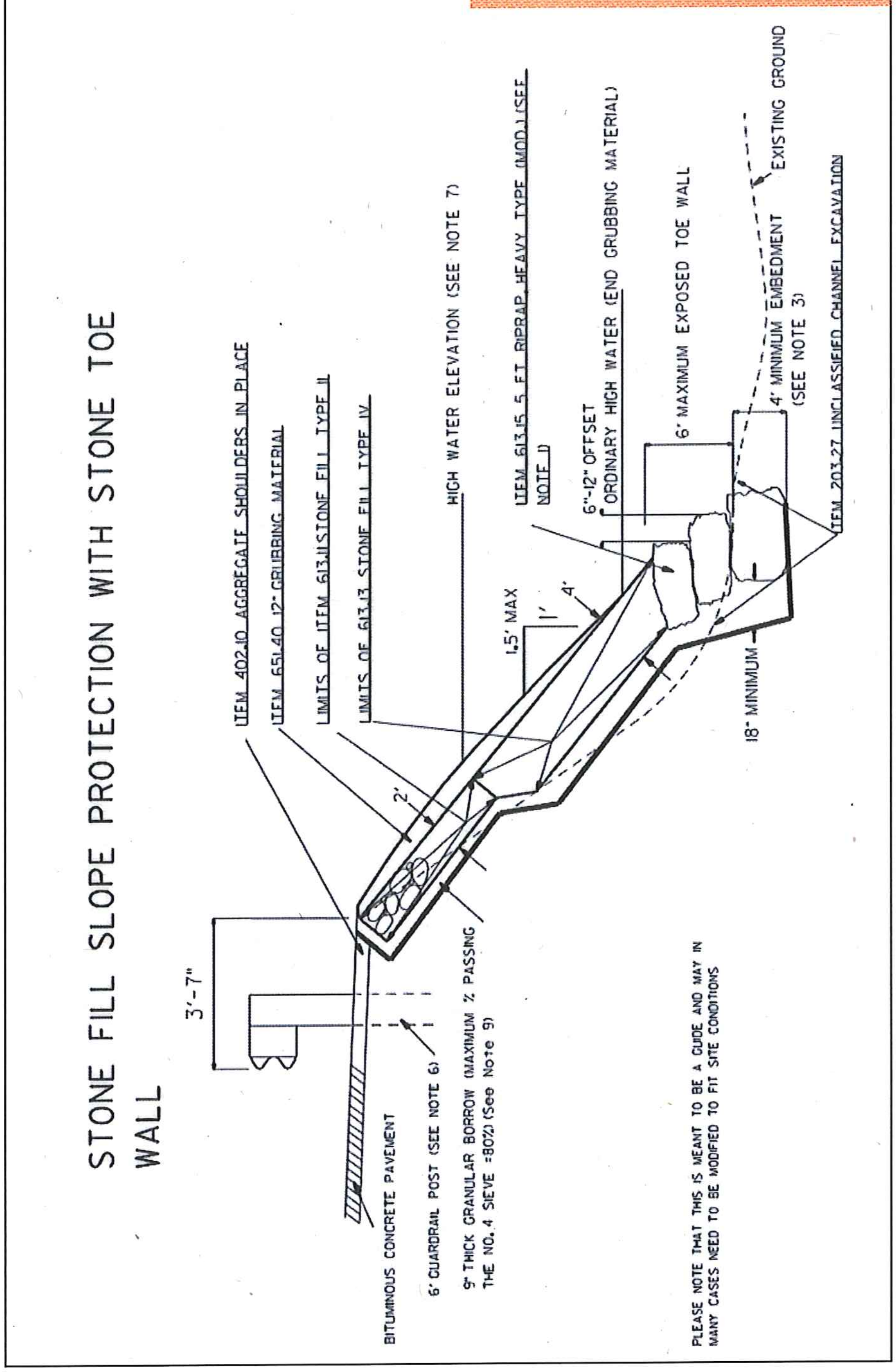
Standard Practices

Placed Rip Rap Wall

Figure 2. *A placed Rip Rap Wall creates lateral channel stability. The steep slope at toe results in less horizontal fill which allows for attainment of full bankfull channel width in confined settings.*

NOTES

1. Stone toe wall shall be constructed with stones of the specified size and in no cases shall the immediate dimension of any stone be less than 3'0".
2. Wall shall be constructed with staggered (ie. running) joints between rocks on adjacent tiers.
3. Footer rock shall be embedded below the channel a minimum of 4'0". Stacked section shall have no more than 6'0" of exposure.
4. Contractor shall carefully select and place individual stones to maximize contact with adjacent stones. Stones are shown as blocks to give contractor the idea of what you would like. They do not need to be cut stone.
5. To extent practical, stones shall dip toward embankment to better resist sliding.


STONE FILL SLOPE PROTECTION WITH STONE TOE WALL
3'-7"
ITEM 402.10 AGGREGATE SHOULDERS IN PLACE
ITEM 651.40 12" GRUBBING MATERIAL
LIMITS OF ITEM 613.11STONE FILL TYPE II
LIMITS OF 613.13 STONE FILL TYPE IV
HIGH WATER ELEVATION (SEE NOTE 7)
ITEM 613.15 5 FT RIPRAP, HEAVY TYPE (MOD.) (SEE NOTE 1)
6"-12" OFFSET
ORDINARY HIGH WATER (END GRUBBING MATERIAL)
6' MAXIMUM EXPOSED TOE WALL
4' MINIMUM EMBEDMENT (SEE NOTE 3)
EXISTING GROUND
ITEM 203.27 UNCLASSIFIED CHANNEL EXCAVATION
1.5' MAX
1'
4'
2'
18" MINIMUM
BITUMINOUS CONCRETE PAVEMENT
6' GUARDRAIL POST (SEE NOTE 6)
9" THICK GRANULAR BORROW (MAXIMUM % PASSING THE NO. 4 SIEVE =80%) (See Note 9)
PLEASE NOTE THAT THIS IS MEANT TO BE A GUIDE AND MAY IN MANY CASES NEED TO BE MODIFIED TO FIT SITE CONDITIONS

Standard Practices

Bed Armor

Figure 3. *Bed armor creates an immobile surface to protect the underlying bed from eroding downward.*

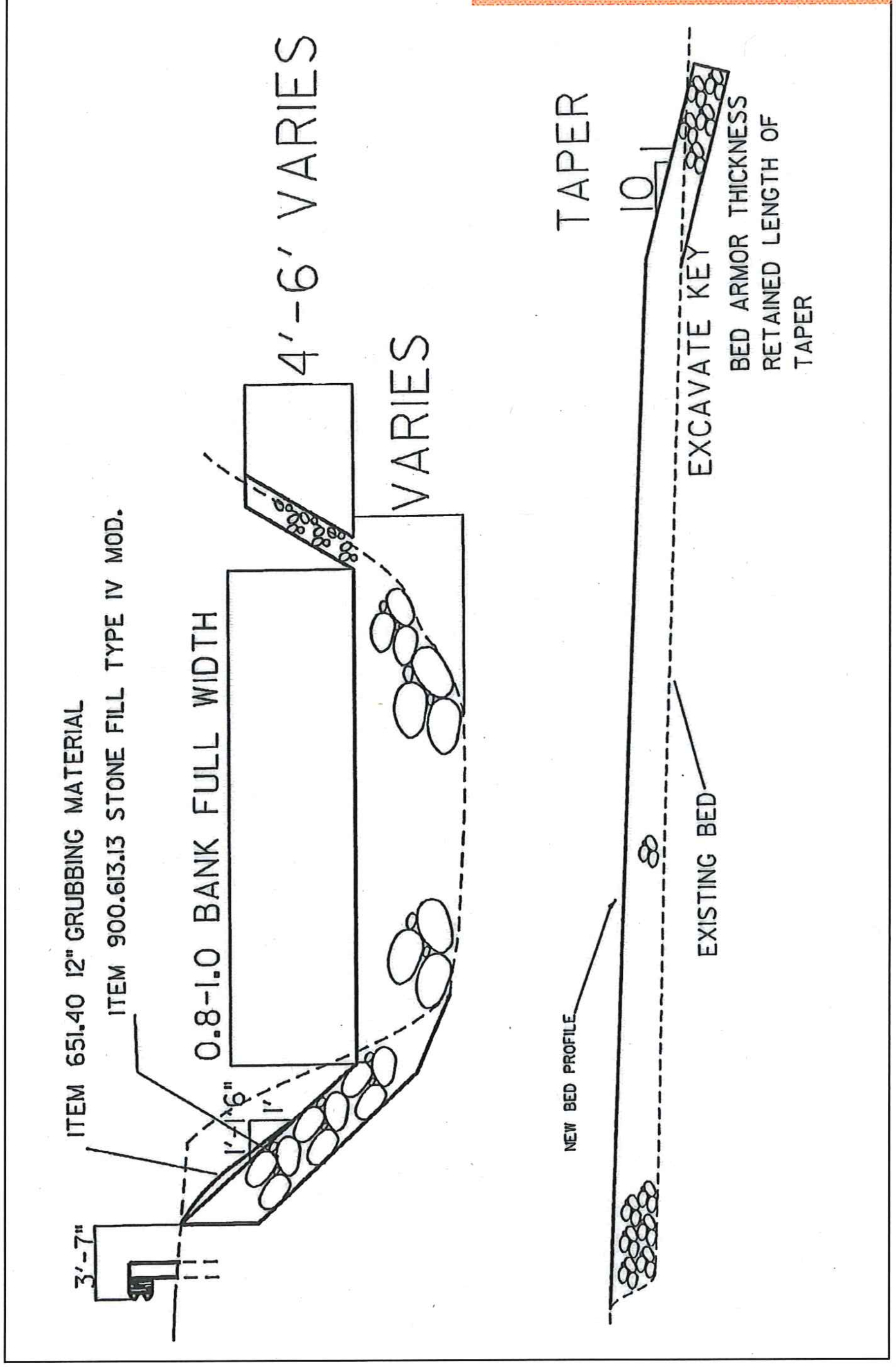
CONSIDERATIONS

- Channel Width and Depth
- Material Size and Gradation
- Thickness
- Up and Downstream Tapers into Channel Bed
- Availability of Bedload to Infill Gaps

NOTES

1. 90% of rock armor by volume must have at least 2 dimensions greater than the average dimension of any existing bed armor particles resistant to the flow.
2. Point of transition either away from toe of roadway embankment or alleviation of channel confinement.

Standard Practices



Standard Practices

Rock Weir

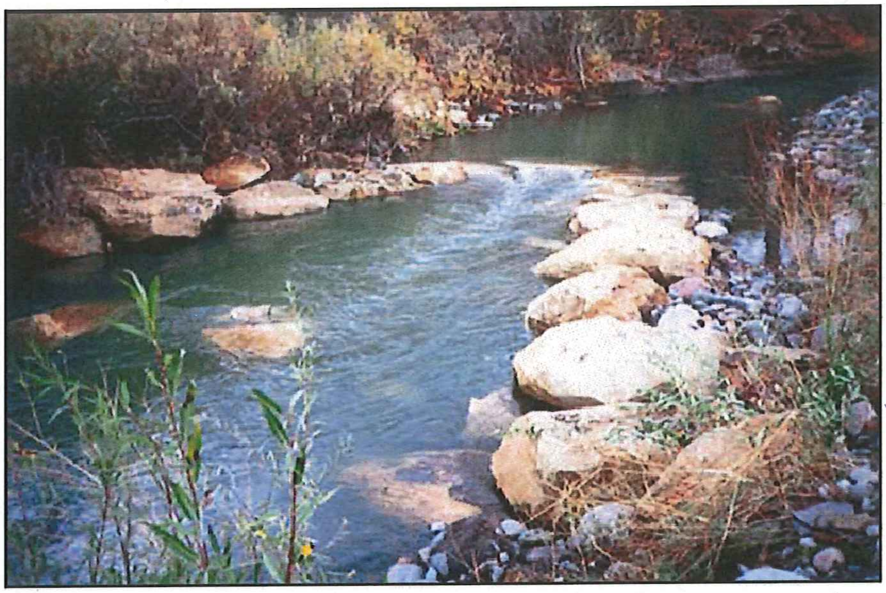


Figure 4. *Rock cross-vanes meet multiple objectives including bed and bank stabilization and sediment transport by creating a stable point in the channel that dissipates and redirects erosive energy as well as habitat by providing deep pools.*

NOTES

1. Rock size should be in the range of 3-5 ft.
2. The footer depth should be 3 times the height of the protrusion of the invert rock (see page 32).
3. The top course should be offset slightly upstream of the footer course to protect against scour at the base of the structure.

Standard Practices

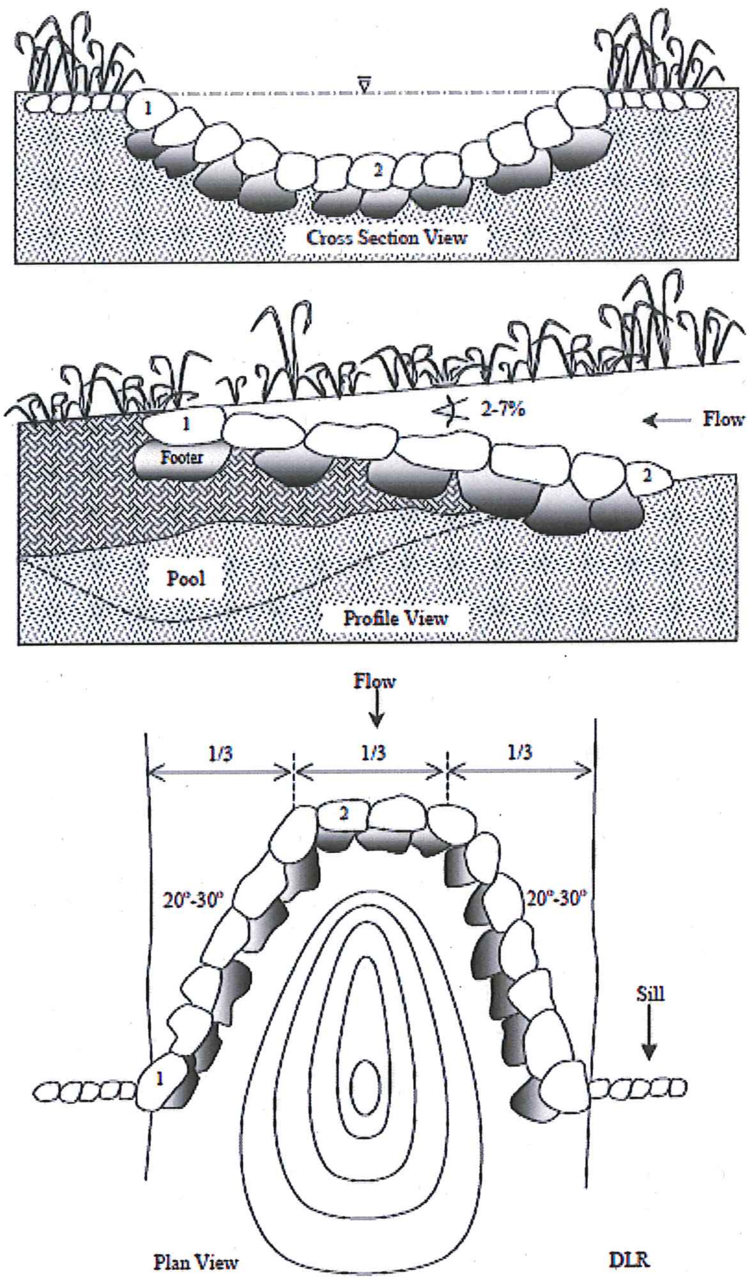


Figure 3. Cross section, profile and plan view of a Cross-Vane

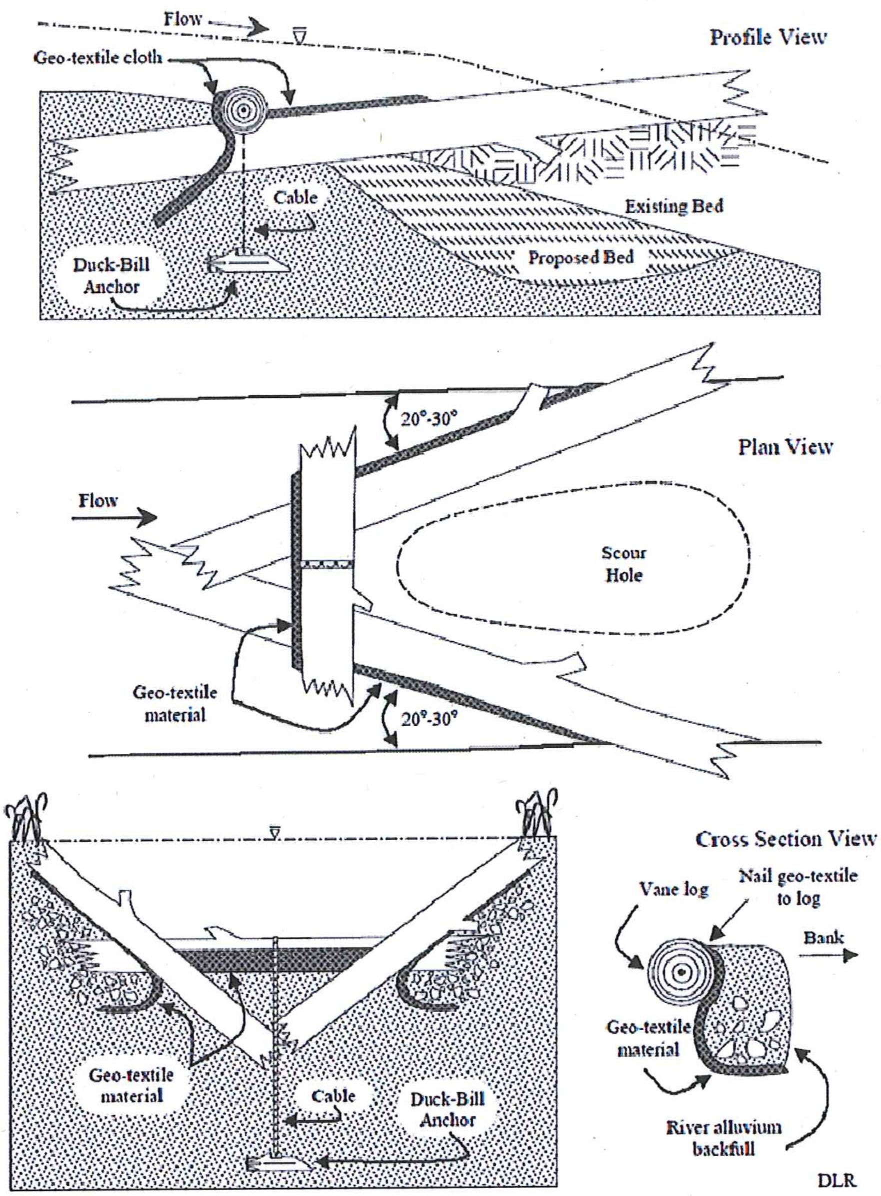
Standard Practices

Log Cross Vane

Figure 5. *Log cross-vanes are an alternative to the rock cross-vanes and meet the same objectives but can be more difficult to construct and have a shorter life expectancy. However, in situations where large rock is unavailable they can be a viable alternative to the rock cross-vane.*

NOTES

1. The invert of the structure is secured using a duck-bill anchor or placement of a large boulder on the ends of the logs.
2. Geo-textile should be used to prevent piping of sediments and undermining of the invert.



Flow
Profile View
Geo-textile cloth
Cable
Existing Bed
Duck-Bill Anchor
Proposed Bed
20°-30°
Plan View
Flow
Scour Hole
Geo-textile material
20°-30°
Cross Section View
Vane log
Nail geo-textile to log
Bank
Geo-textile material
River alluvium backfull
Geo-textile material
Cable
Duck-Bill Anchor
DLR

Standard Practices

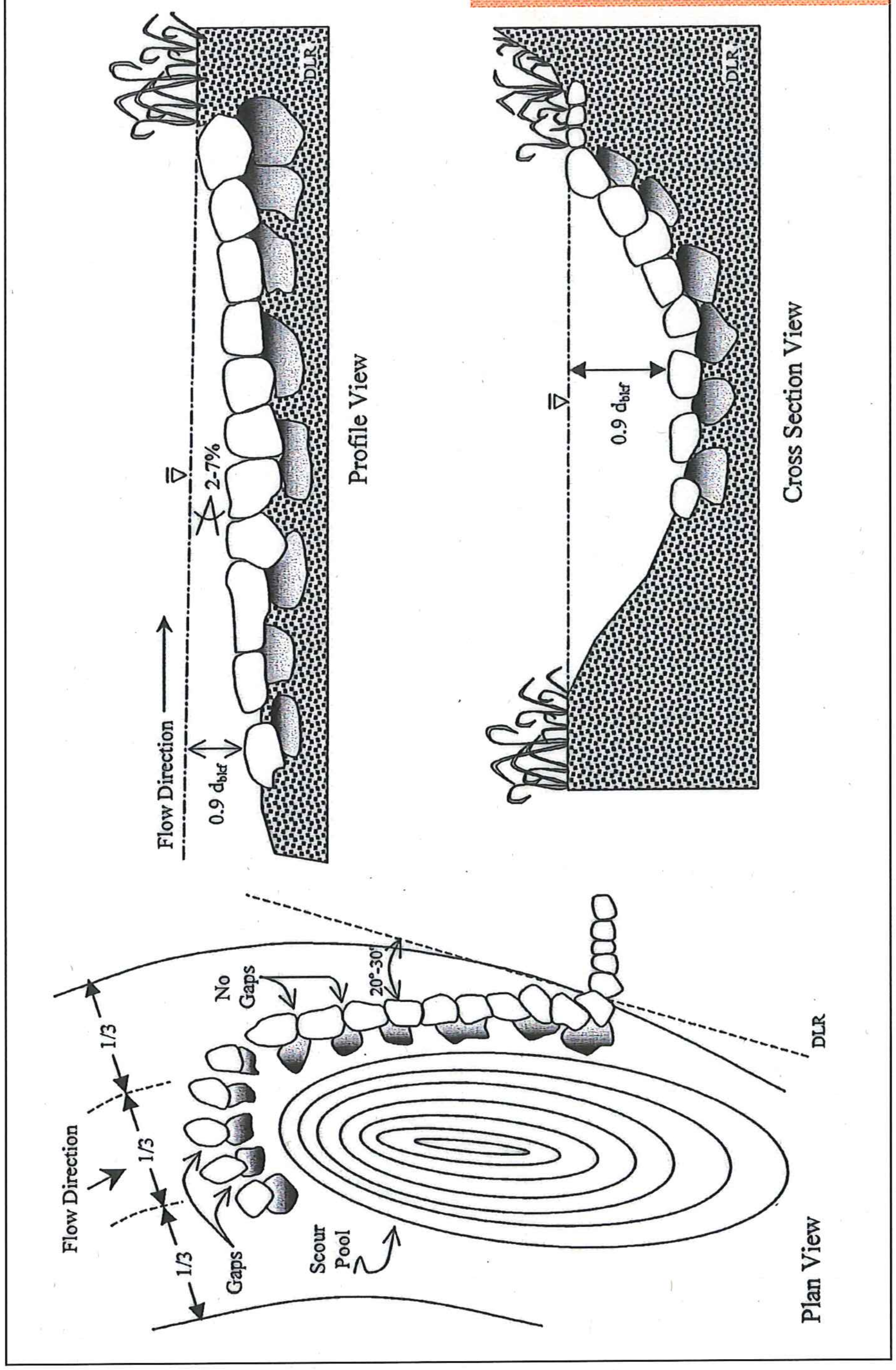
J-Hook Vane

Figure 6. *J-hook vanes meet multiple objectives including bank protection, sediment transport, channel capacity and habitat maintenance by dissipating and redirecting erosive energy into the center of the channel where a deep pool is created.*

NOTES

1. Rock size should be in the range of 3-5ft.
2. The footer depth should be 3 times the height of the protrusion of the invert rock (see page 30).
3. The top course should be offset slightly upstream of the footer course to protect against scour at the base of the structure.
4. Vanes can be constructed without the J-hook component.

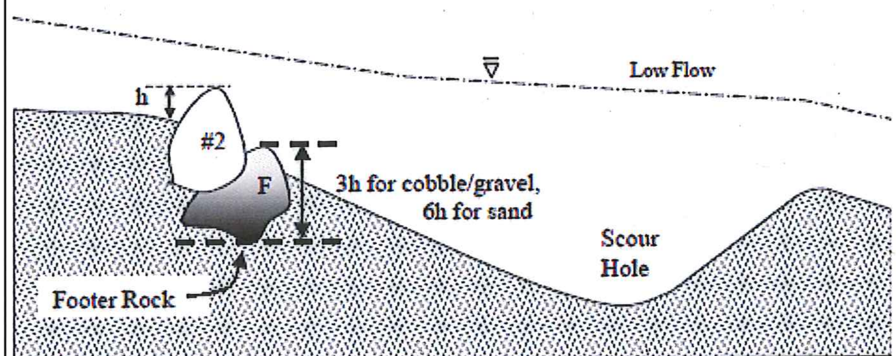
Standard Practices



Standard Practices

Rock Vane Structures: Footer Depth

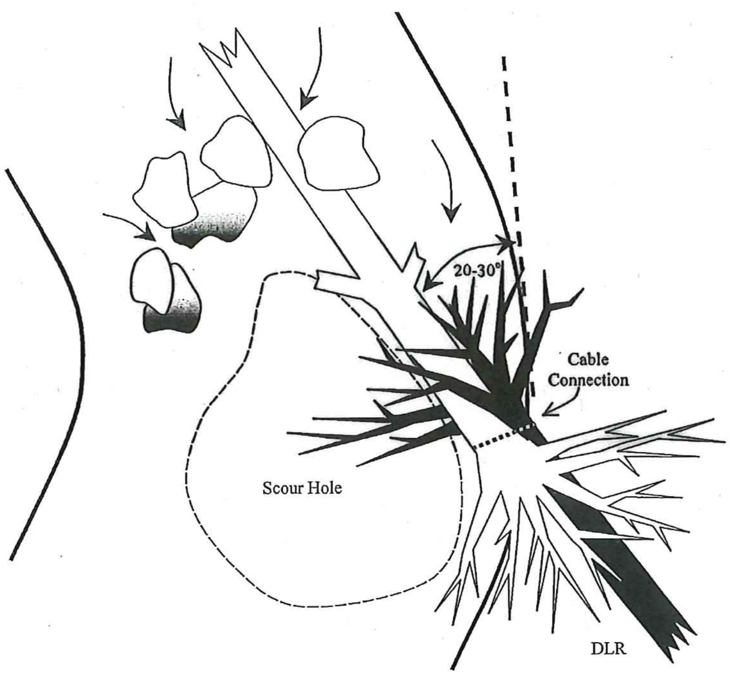
For both the rock cross-vane and the J-hook vane the depth of the footer rock at the invert is 3 times the protrusion height (h) of the top invert rock (#2) in gravel and cobble bed streams. In sand bed streams the footer depth should be 6 times the protrusion height.



Standard Practices

Log J-Hook Vane

Figure 6. *Log J-hook vanes meet the same objectives as the rock J-hook vanes but can be more difficult to construct and have a shorter life expectancy. However, in situations where large rock is unavailable they can be a viable alternative to the rock J-hook vane.*



Standard Practices

Random Boulder Placement

Figure 7. *Random boulder placement meets multiple objectives including channel stability and habitat maintenance by creating roughness that dissipates erosive energy in a way that results in the creation of small scour pools.*

NOTES

1. Boulder placements are suitable on streams where boulders would naturally occur but are absent.
2. Rock size should be 1 to 2 times the largest boulders that would naturally occur on the stream.
3. Clusters of 3 to 5 boulders with one boulder-width between boulders are most effective.
4. Boulders should occupy less than 10% of the bankfull cross-sectional area.

Designing Culverts for River Stability

Culverts sized to the bankfull channel width with sufficient opening height and embedment depth, have a slope similar to the up and downstream channel and horizontally aligned with the channel, will have minimal impact on the hydraulics of the sediment transporting flows and therefore provide for natural channel stability and aquatic organism passage through the structure.

For more information on designing and retrofitting culverts for aquatic organism passage see the Vermont AOP Guidelines at: www.vtfishandwildlife.com/fisheries_AOP.cfm

Vermont General Permit Culvert Requirements	
Span Width	1 x W_{bkf}
Opening Height	4 x D_{bkf}
Embedded Depth	Greater of 30% of O.H. or D_{84}
Profile	Match Channel
AOP	Provided